5th International Conference on Government Education and Tourism Management
(ICoGEMT-5)
Bandung, Indonesia, January 24, 2026

DESIGN AND CONSTRUCTION OF A HAMMER MILL MACHINE FOR GRINDING CORN SEEDS

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Abstract. *This study aims to design, build, and test the performance of a small-medium scale corn kernel grinding hammer mill machine with a 0.5 HP electric motor. The test was conducted using 1 kg of dry corn kernels at three variations of engine speed, namely 492 RPM (speed 1), 903 RPM (speed 2), and 1030 RPM (speed 3), to determine the effect of rotation on milling time and fineness of the results. The results showed that at 492 RPM the milling time was 32 seconds with a result size of 6.5 mm, at 903 RPM the time decreased to 23 seconds with a size of 2 mm, and at 1030 RPM the fastest time was 15 seconds with the finest result size of 1 mm, so it can be concluded that increasing the engine speed increases the hammer impact energy, speeds up the milling process, and produces finer particles, with optimal performance achieved at 1030 RPM.*

Keywords: *Corn Kernels; Fineness of the Grind; Grinding Time; Hammer Mill; Machine Speed.*

1. INTRODUCTION

Indonesia is an agricultural country with significant corn production, strategically important for the food and animal feed sectors. Data from the Central Statistics Agency (BPS) indicates that in 2024, the harvested area for shelled corn will reach approximately 2.55 million hectares, with production reaching 15.14 million tons, an increase from 14.77 million tons in 2023. This increase in production demonstrates the significant potential of corn for development as a food ingredient, animal feed, and raw material for the processing industry.

The abundant availability of corn opens up opportunities for agro-industry development, particularly in processing it into flour and animal feed with higher added value. To support national food security and feed self-sufficiency, appropriate, affordable processing technology is needed, tailored to the needs of micro, small, and medium enterprises (MSMEs) and small- and medium-scale livestock farmers. However, exploiting this potential still faces the challenge of limited efficient processing technology.

A hammer mill is a commonly used flouring machine because it operates on a collision mechanism, producing fine particles. In mechanical engineering, hammer mill design requires a thorough study of key components such as the rotor, hammers, flour housing, power transmission system, and the selection of materials capable of withstanding dynamic loads. Several studies have shown that hammer mill performance is influenced by hammer design, rotational speed, and sieve configuration.

The main problem faced by MSMEs is the mismatch between available machinery and operational needs. Large-scale industrial machinery is generally expensive, energy-intensive, and uneconomical for medium-scale operations, while traditional or non-standard machinery often produces non-uniform particle sizes and is less efficient. Particle size inhomogeneity impacts feed and flour quality, affecting digestibility, nutrient distribution, and product consistency.

Various studies have shown that hammer mill design innovations, such as varying hammer angles, sieve sizes, and speed settings, can increase efficiency and produce finer, more uniform particle sizes. Therefore, the research, "Design and Construction of a Hammer Mill for Grinding Corn Grains," is crucial for producing a prototype for a small-to-medium-scale machine that is efficient, economical, easy to maintain, and meets the needs of MSMEs

2. LITERATURE REVIEW

2.1 Hammer Mill

A hammer mill is a size reduction machine that operates on the principle of impact. The size reduction process occurs due to the impact energy generated by the high-speed rotor rotation that carries the hammers within the grinding chamber. Material entering through the hopper undergoes repeated impacts with the hammers until it fractures and fragmentes, then passes through a screen after reaching a certain particle size. This mechanism makes hammer mills effective for medium to fine size reduction processes on various dry materials.

Hammer mills offer high flexibility because the particle size of the milled product can be controlled by selecting the screen size and adjusting operational parameters such as rotor speed and the number of hammers. Hammer design, grinding chamber shape, and screen configuration influence production capacity, particle homogeneity, and energy consumption. Therefore, hammer mills are widely used in the agricultural processing industry because they can process a variety of materials with adjustable fineness.

In the agro-industrial sector, hammer mills play a crucial role in grinding agricultural raw materials such as corn, soybeans, dried tubers, and biomass. This size reduction process aims to increase the material's utility value, simplify subsequent processing, and improve the homogeneity of the mixture. In the animal feed industry, the particle size of the milled product significantly impacts digestibility, nutritional efficiency, and feed quality. Hammer mills allow particle size adjustments to suit livestock needs, thus supporting production efficiency and improving overall livestock performance.

2.2 Hammer Mill Working Principle

The working principle of a hammer mill is based on a crushing mechanism through impact force generated by the high-speed rotor rotation. The rotor carries a number of tangentially rotating hammers, giving it the kinetic energy to break up the material entering the grinding chamber. The resulting impact force can exceed the material's strength, causing fracture and gradual size reduction. This mechanism makes hammer mills effective for processing dry, brittle, and organic materials.

During the operational process, material is fed through a hopper and falls into the grinding chamber due to gravity. Inside the grinding chamber, the material experiences repeated impacts from rapidly rotating hammers and friction with the grinding chamber walls. The rotor's centrifugal force helps direct the material to the outside of the grinding chamber, increasing the intensity of the impacts. The number and effectiveness of impacts are influenced by rotor speed, hammer configuration, and the material's physical properties.

Material that has reached a certain size will pass through a screen that acts as a particle size filter. Larger particles are retained and further milled until they reach the desired size. This continuous process allows the hammer mill to produce relatively uniform particle sizes with high efficiency through a combination of impact, friction, and screening mechanisms in one integrated system.

2.3 Hammer Mill Machine Components

1. *Rotor*

The rotor is the main component of a hammer mill which functions as a rotating part where the hammer is attached. The rotor rotates at high speed so that it produces impact energy which is used to break the material into smaller sizes.Rotor performance significantly determines the effectiveness of the milling process, production capacity, and the quality and fineness of the milled product. Based on the number of shafts and their mounting configuration, the rotors in corn grinding machines can be divided into several types. The single rotor is the most commonly used type due to its simple construction, easy maintenance, and strong enough to grind materials such as corn and feed grains. Meanwhile, the double rotor uses two shafts, both equipped with hammers, resulting in greater impact intensity. This type is generally used in large-capacity machines or for grinding harder materials.

Based on the hammer mounting method, rotors can use fixed hammers or swinging hammers. In fixed hammer rotors, the hammers are rigidly mounted, resulting in stronger and more effective impact force on hard materials. However, this configuration has the disadvantage of faster hammer wear and the risk of damage if they collide with foreign objects. In contrast, swinging hammer rotors allow the hammers to move freely during impact, resulting in greater safety, lower vibration, and extended component life. Therefore, this type is most commonly used in modern hammer mills.

Additionally, there are rotors with a larger number of hammers, known as multi-blade rotors. This configuration increases the impact frequency, resulting in faster grinding and more uniform particle sizes. However, this type of rotor requires more drive power than standard designs.

2. Hammer

The hammer is the main component of a hammer mill, crushing material through direct impact force. As the rotor rotates, the hammer generates impact energy, causing the material to fracture and reduce in size. The hammer's design affects grinding capacity, the fineness of the results, and the machine's lifespan.

Based on their shape, hammers are divided into straight hammers, which are commonly used because they produce stable impacts and are easy to produce, and swing or notched hammers, which have grooves to increase impact force and homogeneity of the grind. Tapered hammers, with their tapered tips, produce more focused impacts and are suitable for fine grinding, while hard-faced hammers are coated with a hard material to increase wear resistance under severe operating conditions.

In terms of installation, the swinging hammer is hinged so it can move freely with the rotor rotation. This configuration is safer, reduces wear, and is widely used in hammer mills for grinding corn kernels.

3. Housing

Housing or grinding chamber is a closed compartment where the material crushing process takes place, which functions to withstand intensive collisions between the hammer and the material and direct the flow of material to move effectively towards the screen. Based on its shape and function, the housing can be a cylindrical housing with cylindrical walls that produce a more stable material flow and even distribution of collisions, rectangular or box-type housing which is simpler to manufacture but has a less even flow pattern, a narrowed or conical housing that accelerates the flow of material to the screen, a housing with an internal deflector thatequipped with a guide plate to increase turbulence and impact effectiveness, insulated housing or vibration damper to reduce noise and vibration of the machine's work, as well as a cooling housing equipped with a cooling system to prevent temperature increases, especially for materials that are sensitive to heat.

4. Screen

Screen is a filter component that determines the final size of the milled particles, located at the bottom of the milling chamber with holes of a certain diameter so that particles that have not met the size will be retained and re-impacted until the desired fineness is achieved. Commonly used screen types include round hole screens with round holes to produce a uniform particle size distribution, slotted screens with longitudinal slits to increase output capacity and are suitable for coarse to medium grinding, perforated steel screens that have high wear resistance and stability for continuous operation, expanded metal screens with a mesh structure that provides smoother material flow but lower wear resistance, and hardened steel screens that have gone through a hardening process so they are very resistant to friction and repeated impacts, especially for abrasive materials and intensive operations.

5. *Hopper*

The hopper serves as a container for feeding material into the grinding chamber. The hopper must be designed to allow material to flow steadily without causing blockages.

6. *Drive Motor*

The drive motor functions to convert electrical or chemical energy into mechanical energy to rotate the rotor, so its selection must be adjusted to the production capacity, rotational speed, and workload so that the machine's performance is stable and durable. Commonly used motor types include AC electric motors, both 1 phase for small-medium capacity and 3 phase for large capacity and continuous operation because they are strong and low maintenance, DC electric motors are chosen when smooth and precise speed regulation is required, gasoline motors are suitable for portable applications and small-medium capacity without electricity dependence, and diesel motors that have large torque and are efficient for heavy loads and long-term operation in locations with limited electricity supply.

Figure 1. Flow chart

3. RESEARCH METHODS

Several stages of research are listed in the flowchart above as follows:

1. *Identification of Problems*

   Requirements identification was conducted by considering the use of a corn-chopping hammer mill. The primary requirements formulated included a 5 kg capacity per process, stable grinding results, ease of operation, user safety, and ease of maintenance. The needs analysis aimed to identify the machine's technical specifications, including production capacity, milled grain size, and power source (electricity), which would serve as a reference in determining subsequent design parameters.
2. *Literature Study*

   Literature studies were conducted to obtain a theoretical basis through a study of existing hammer mill machines, the working principles of the crushing mechanism, the characteristics of the main components, as well as considerations for material selection and construction design from various scientific sources.
3. *Design and Drafting*

   The frame design was created in 3D using SolidWorks software based on collected field data. A detailed CAD model was prepared to accurately represent the shape of the corn-chopping hammer mill. The initial design phase is the conceptualization phase, which includes creating a rough sketch, selecting a hammer type based on the characteristics of the material to be milled, and determining the basic dimensions of key components, such as the rotor cylinder diameter and housing size.

4. *Tool Making*
   Tool making is the physical realization stage through the process of cutting, forming, and machining materials according to the working drawings, which is then continued with systematic assembly of components to produce a functional hammer mill machine.
5. *Data Analysis*
   Data analysis in the form of machine testing was carried out to validate the prototype performance by evaluating the actual milling capacity parameters, the consistency of the particle size of the milled corn kernels. The object parameters used were 1 kg of dry corn kernels using a 0.5 hp electric motor with 3 types of speed acceleration starting from speed 1, speed 2, speed 3.

4. RESULTS AND DISCUSSION

4.1 Hammer Mill Machine Test Results

Based on the research results, to evaluate the machine's working capacity in the material crushing process, an electric motor drive of 0.5 hp with a capacity of 5 kg was used. The data obtained from this test were then analyzed to assess the suitability of the machine's performance with the design that had been made and as a basis for evaluating and developing the design in a more optimal direction.

Based on the data results above, angular velocity is used to determine the impact energy produced by the hammer mill.

Formula:

$$\omega = \frac{2\pi n}{60}$$

Information:
ω = angular velocity (rad/s)
n = engine speed (RPM)

a. Speed 1 (492 RPM)

$$\omega = \frac{2\pi(492)}{60} = 51{,}52\ \text{rad/s}$$

b. Speed 2 (903 RPM)

$$\omega = \frac{2\pi(903)}{60} = 94{,}56\ \text{rad/s}$$

c. Speed 3 (1030 RPM)

$$\omega = \frac{2\pi(1030)}{60} = 107{,}82\ rad/s$$

Theoretically, a hammer's kinetic energy is directly proportional to the square of its angular velocity. This means that an increase in angular velocity will result in a significantly greater increase in impact energy, even if the RPM increase is not significant.

Based on the calculation results:

1. Speed 1: 51.52 rad/s
2. Speed 2: 94.56 rad/s
3. Speed 3: 107.82 rad/s

After obtaining the rotation results, the hammer mill machine is in a condition after the engine rotation data has been collected. This machine is the result of a manufacturing process that includes the design stages, material cutting, welding the frame and housing, installing the shaft, bearings, and installing the drive motor. After the fabrication and assembly process is completed, an initial inspection is carried out to ensure the suitability of dimensions, connection strength, and alignment of the shaft to the bearings. Next, the machine is operated without load to obtain engine rotation data as an initial testing stage. This condition indicates that the machine has gone through the complete manufacturing and assembly stages, and is in a state of readiness to proceed to the performance testing stage, such as testing the material crushing ability, production capacity, and operational stability based on the engine rotation parameters that have been obtained.

Figure 1. Corn Grinding Hammer Mill Machine

Based on Figure 1 the testing of the corn kernel grinding hammer mill machine was carried out with three variations of the machine rotation speed which was set using a dimmer starting from speed 1, Speed 2, Speed 3. The parameters observed included the machine rotation (RPM), grinding time, and the size of the ground results. Corn kernels were used as much as 1 kg. Data collection was done by inserting corn kernels into the machine, so that the machine would grind the corn kernels into the filter.

Figure 2. Corn Chopper Data Collection Process

From the testing process, the data obtained from each variation of machine speed, milling time, and material output results were then recorded and arranged in tabular form to facilitate analysis of the relationship between machine speed, process time, and the quality of milling results, which are presented in Table 1.

Table 1. Corn Chopper Data Results

No	Dimmer	Rotation (RPM)	Time (seconds)	Result Size (mm)
1	Speed 1	492	32	6.5
2	Speed 2	903	23	2.0
3	Speed 3	1030	15	1.0

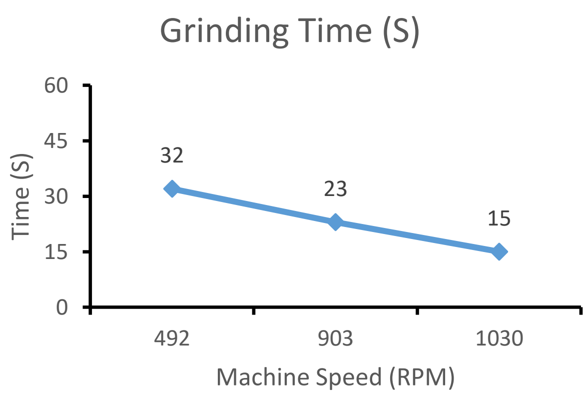
Based on the test results, it is clear that increasing the engine speed from 492 RPM to 1030 RPM has a significant impact on the grinding time and the level of fineness of the grinded results.

At low rotational speed (492 RPM), the resulting angular velocity is 51.52 rad/s. This value results in relatively low kinetic energy of the hammer, so the impact between the hammer and the corn kernels is not optimal. As a result, the corn kernel crushing process is slower and produces coarser particle sizes, averaging 6.5 mm. This indicates that under these conditions, the crushing mechanism is dominated by pressure and friction, rather than high-energy impacts.

When the engine speed was increased to 903 RPM, the angular velocity increased to 94.56 rad/s. This increase resulted in greater impact energy from the hammer on the corn kernels. The impact frequency also increased, resulting in repeated crushing of the corn kernels in a shorter time. Consequently, the grinding time was reduced to 23 seconds, and the grind size decreased significantly to 2 mm. This indicates that the machine was operating within its effective rotational range for the grinding process.

4.2 Relationship between Machine Rotation and Milling Time and Results

Based on the test data presented in tabular form, the data is entered into a graph to analyze the effect of rotational speed on milling time and the results of the corn fineness measurement.



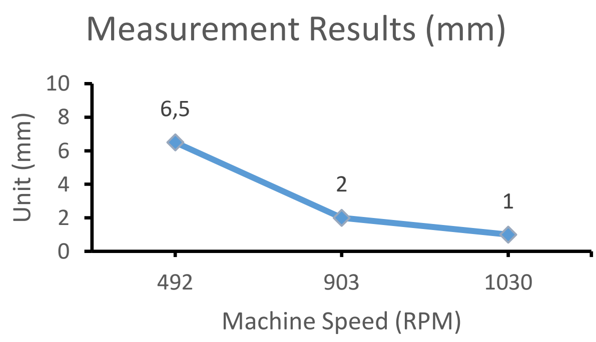
Graph 1. Relationship between Machine Speed and Milling Time

Based on the graph showing the relationship between Machine Speed (RPM) and Grinding Time (seconds), a clear trend is seen that the two variables have an inverse relationship. This means that increasing machine speed causes grinding time to decrease.

From the test results obtained:

1. 492 RPM → 32 seconds
2. 903 RPM → 23 seconds
3. 1030 RPM → 15 seconds

The reduction in grinding time from 32 seconds to 15 seconds indicates that increasing the machine speed significantly speeds up the process of crushing corn kernels.



Graph 2. Relationship between Machine Speed and Milling Result Size

The graph shows that the grind size decreases as the engine speed increases. At 492 RPM, the average size is 6.5 mm, then decreases to 2.0 mm at 903 RPM, and reaches the finest size of 1.0 mm at 1030 RPM. The inclusion of values at each point emphasizes the relationship between engine speed and the level of grind fineness.

CONCLUSION

Based on the design and testing results of the corn kernel grinding hammer mill machine, it can be concluded that the machine from the dimmer speed 1, speed 2, speed 3 rotation, which was made was able to function well in the grinding process. The engine rotation significantly affected the grinding time and the level of fineness of the grinding results. Speed 1 was obtained at 492 rpm for 32 seconds with a fineness of 6.5 mm of corn kernels, for speed 2 it was obtained at 903 rpm for 23 seconds with a fineness of 2 mm, and speed 3 was obtained at 1030 rpm for 15 seconds with a fineness of 1 mm. The higher the engine rotation, the shorter the grinding time and the smoother the grinding results. The best performance was obtained at 1030 RPM with a grinding time of 15 seconds and a grinding size of 1 mm.

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